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An Evaluation of Seeding Rangeland with Pellets

Howard W. Chadwick
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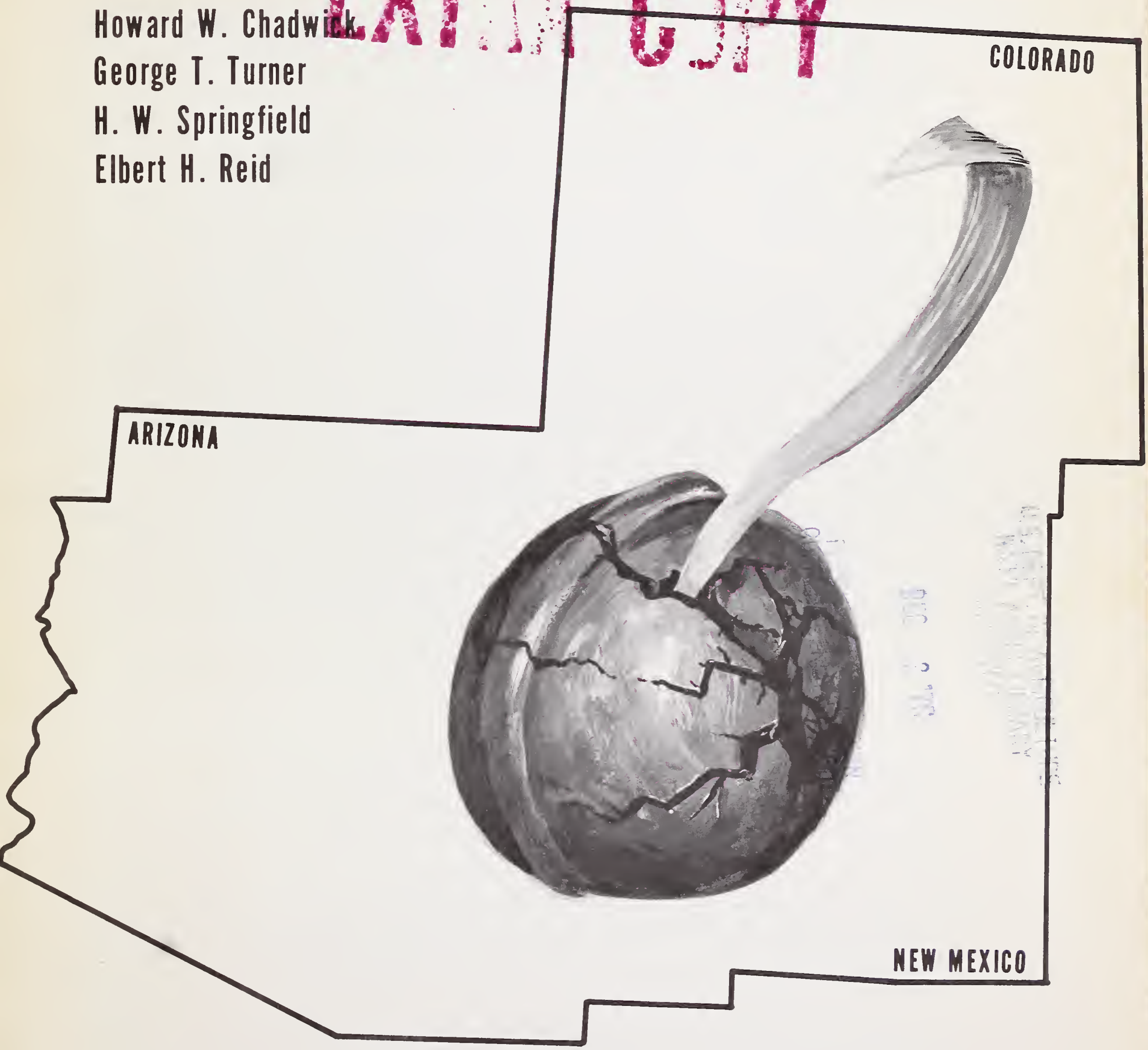

Rocky Mountain Forest and Experiment Station —— Forest Service, U. S. Department of Agriculture

COMMON AND BOTANICAL NAMES OF PLANTS MENTIONED

Annual Grasses

Grama, needle	*Bouteloua aristidoides* (H.B.K.) Griseb.
Grama, sixweeks	*B. barbata* Lag.
Threeawn, sixweeks	*Aristida adscensionis* L.

Perennial Grasses

Bluegrass, Kentucky	*Poa pratensis* L.
Bluestem, Turkestan	*Andropogon ischaemum* L.
Brome, smooth	*Bromus inermis* Leyss.
Grama, blue	*Bouteloua gracilis* (H.B.K.) Lag.
Lovegrass, Boer	*Eragrostis chloromelas* Steud.
Lovegrass, Lehmann	*E. lehmanniana* Nees
Lovegrass, weeping	*E. curvula* (Schrad.) Nees
Lovegrass, Wilman	*E. superba* Peyr.
Orchardgrass	*Dactylis glomerata* L.
Ricegrass, Indian	*Oryzopsis hymenoides* (Roem. & Schult.) Ricker
Timothy	*Phleum pratense* L.
Wheatgrass, crested	*Agropyron desertorum* (Fisch.) Schult.
Wheatgrass, intermediate	*A. intermedium* (Host) Beauv.
Wheatgrass, western	*A. smithii* Rydb.
Wildrye, Russian	*Elymus junceus* Fisch.

Forbs

Alfalfa	*Medicago sativa* L.
Burroweed	*Haplopappus tenuisectus* (Greene) Blake
Clover, alsike	*Trifolium hybridum* L.
Clover, red	*T. pratense* L.
Sweetclover, yellow	*Melilotus officinalis* (L.) Lam.

Trees and Shrubs

Cholla, Sonora jumping	*Opuntia fulgida* Engelm.
Fir, subalpine	*Abies lasiocarpa* (Hook.) Nutt.
Juniper, one-seed	*Juniperus monosperma* (Engelm.) Sarg.
Mesquite, velvet	*Prosopis juliflora velutina* (Woot.) Sarg.
Oak, shrub live	*Quercus turbinella* Greene
Pine, pinyon	*Pinus edulis* Engelm.
Pricklypear, Engelmann	*Opuntia engelmannii* Salm-Dyck
Rabbitbrush, Douglas	*Chrysothamnus viscidiflorus* (Hook.) Nutt.
Sagebrush, big	*Artemisia tridentata* Nutt.
Snakeweed, broom	*Gutierrezia sarothrae* (Pursh) Britt. & Rusby
Spruce, Engelmann	*Picea engelmannii* Parry

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An Evaluation of Seeding Rangeland with Pellets[1]

by

Howard W. Chadwick, Range Scientist

George T. Turner, Plant Ecologist

H. W. Springfield, Principal Range Scientist

and

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Rocky Mountain Forest and Range Experiment Station[2]

[1]The assistance given to the project by Dr. Lytle S. Adams, Tucson, Arizona is gratefully acknowledged, especially his patience in manufacturing the numerous lots of pellets, without which the studies could not have been undertaken.

[2]Central headquarters maintained at Fort Collins in cooperation with Colorado State University. Turner and Reid are located at Fort Collins; Springfield, at Albuquerque, in cooperation with the University of New Mexico; Chadwick, formerly at Tempe, in cooperation with Arizona State University, is now with the Bureau of Outdoor Recreation, Seattle, Washington.

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An Evaluation of Seeding Rangeland With Pellets

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Summary

A study of the pellet method for range seeding was conducted from July 1963 through June 1965 by the Rocky Mountain Forest and Range Experiment Station, a research unit of the Forest Service, U. S. Department of Agriculture.

Studies included laboratory and greenhouse tests, field plot trials, and aerial seedings at various locations in Arizona, New Mexico, and Colorado.

Laboratory and greenhouse tests included determining (1) seed and pellet viability, and the number of seeds contained within pellets; (2) physical characteristics of pellets, including their durability under simulated rainfall and fluctuating temperature; (3) nature of seedling emergence and development; (4) acceptability of pelleted seed by rodents; (5) investigation of coatings and additives to improve pellet characteristics; and (6) suitability of pellets as carriers of legume inoculant.

Field plot trials were made to determine pellet durability, to determine the feasibility of interseeding rangeland with a legume through use of inoculated pellets, and to compare results of seeding pelleted and nonpelleted seed.

Aerial seedings were larger scale seedings at locations where good results from range seeding usually are expected. The three areas represent a wide range of environmental conditions, from semidesert range on which 13 inches of annual rainfall may be expected to high mountains that receive 30 inches or more of rain and snow.

Results of laboratory and greenhouse tests indicate that pellets containing small seeds usually are highly viable at time of manufacture, and that viability is retained at least 12 months provided proper care is taken in pellet manufacture, drying, and storage. Large seeds were commonly damaged by the pelleting process. Field plot trials and aerial seedings showed that: (1) some seedlings generally developed from seedings made by the pellet method; (2) seedling stands from pellet seeding were sparser than from methods usually employed; and (3) the sparser stands from pellet seeding were due partly to low seeding rates, partly to rapid breakdown of pellets, and partly to unexplained causes.

Specific results from the 2-year study are:

1. In laboratory tests, seedlings developed from 70 to 100 percent of the pellets that contained seed of Boer,[3] Lehmann, and weeping lovegrasses, alsike and red clovers, alfalfa, intermediate wheatgrass, Russian wildrye, and timothy; 50 to 70 percent of the pellets containing Wilman lovegrass, crested wheatgrass, and orchardgrass seed produced seedlings. Poorer results were obtained with yellow sweetclover, smooth brome, Indian ricegrass, and Turkestan bluestem.
2. Pellets air-dried after manufacture generally retained high viablitity at least 12 months. On the other hand, pellets not dried but stored under relatively high temperatures in closed containers lost much of their viability within 3 to 6 months.
3. Clay pellets disintegrated within a relatively short time when exposed to artificial or natural rain, especially if the rains were of fairly high intensity and long duration. Coating the pellets with methyl cellulose or latex slowed disintegration. Incorporation of methyl cellulose and other additives with the pelleting clay also delayed disintegration. None of the coatings or additives tested significantly improved seedling emergence or development.
4. Alternate freezing and thawing caused only minor disintegration of pellets compared with that caused by rain.
5. Incorporation of 2 percent by weight of potassium nitrate fertilizer into pellets tended to increase seedling height growth.
6. Laboratory tests indicated that pelleting effectively reduced grass seed consumption by deer mice (Peromyscus), a common seed-eating range rodent.
7. Results from both greenhouse and field trials suggest that clay pellets may serve effectively as a carrier of legume inoculant, and thereby improve the possibility of successfully interseeding rangelands with legumes. Inoculant bacteria (Rhizobia) lived at least 8 months after being incorporated into clay pellets, and caused nodules to form on roots of most seedlings.

[3]*Common and botanical names of plants mentioned are listed inside the front cover.*

8. In aerial seeding tests, grass plants became established from pellets under widely different conditions. The number of plants averaged one for every seven pellets distributed on a plowed sagebrush range and one for nine pellets on a burned-over spruce area. However, only one plant became established for every 188 pellets distributed on a desert grass-shrub range on which mesquite had been controlled. In each case the grass stand from pellet seeding was sparser than the check stand produced by the seeding method usually used to seed such areas.
9. Broadcasting of pelleted and nonpelleted seed on an unprepared seedbed in sagebrush failed to produce a grass stand, which indicates that reduction of competing vegetation is as essential with pellet seeding as with other seeding methods.
10. Cost of aerial seeding with clay pellets ranged from \$7 to \$14 per acre, substantially higher than that for seeding by methods commonly used.
11. Progress was made toward developing a durable, lightweight pellet that would protect seed from rodents and insects until conditions become favorable for seed germination and seedling establishment.

Introduction

Pellet seeding is intended to meet the need for an inexpensive, practical method of seeding large areas of depleted rangeland, especially where rough terrain or other factors preclude the use of mechanical equipment. The pellet is viewed as a vehicle for carrying the seed to the ground from an airplane, and for protecting the seed where it falls until a seedling becomes established. In theory, the pellet could provide the essentials for successful seed germination and seedling establishment—seed, nutrients, and coverage of the seed. Only moisture would be lacking, which is provided by natural precipitation. Distribution of a suitable pellet by airplane would make possible the seeding of large areas of rugged terrain in a short time.

Range seeding is a recognized practice. Millions of acres of depleted rangeland have been seeded successfully. Years of research and experience have shown that, to be successful, range seeding generally must follow certain principles, most important of which are: (1) Use plant species adapted to the area; (2) reduce competition from existing vegetation sufficiently to allow the seeded species to become established, and (3) cover the seeds with soil (Plummer et al. 1955). In addition, growing conditions must be favorable from time of seed germination until the new plants are well established. To meet these requirements, intensive land treatments usually are necessary. To be economically feasible, range seeding generally must be confined to potentially productive areas that are readily accessible to heavy equipment. Many years will be required to seed the vast areas of rangeland needing revegetation unless more efficient methods are developed.

The desire to seed quickly and cheaply the extensive areas of rangeland that are inaccessible or unsuitable for seeding by ground equipment led to aerial distribution of seed. Aerial seeding has proved especially satisfactory when regular seed is broadcast into the ashes of recently burned-over timberland or brushland, and when falling leaves can be expected to cover the seed. The latter practice is recommended, however, only where existing vegetation offers little competition. Such aerial seeding generally has not proved satisfactory on burned-over sagebrush land where the ash layer is thin, or on other unplowed areas. Seeding of Lehmann lovegrass on unplowed areas has been an exception; good stands have been obtained by aerial seeding on bare ground following mesquite control.

In an attempt to expedite and promote aerial seeding, pellets containing seed were developed commercially a number of years ago. Among the advantages claimed for pellets were the following (Ashley 1945, Haystead 1945, Kimball 1949):

1. The pellet provides seed coverage and protection from insects and rodent depredation.
2. Use of pellets insures more accurate placement of aerially broadcast seed, and results in more uniform distribution.
3. The pellet, when used as a medium for fertilizer, fungicide, or insecticide, promotes growth and survival of young seedlings.
4. Pelleting facilitates handling and broadcasting of small seeds.

Previous Work With Pellets

Comparative tests during the past 20 years have shown that nonpelleted seed has generally produced more satisfactory results than pelleted seed. In southeastern Utah, aerial broadcasting of nonpelleted grass seed at a rate of 10 pounds per acre produced, on the average, as few as one seedling per square foot in a mountain brush type, and as many as 11.35 per square foot under an aspen canopy (Bleak and Phillips 1950). Comparable seedings with pelleted seed produced up to 0.44 seedling per square foot. Pellets were broadcast at rates of one and two pellets per square foot, which approximated 1.2 and 2.4 pounds of seed per acre. Seedling stands produced by two pellets per square foot were not appreciably better than those from one. Included in those tests were seven plant species broadcast over some 8,000 acres on which four vegetation types were present: aspen,

ponderosa pine, mountain brush, and pinyon-juniper. All first-year grass stands from pelleted seed were rated "very poor;" those from nonpelleted seed ranged from "medium" to "very good" except for one "poor" stand.

In supplemental laboratory tests, 11 to 78 percent of pellets produced one or more seedlings, compared with 62 to 98 percent germination for nonpelleted seed. Similarly, emergence of seedlings in nursery plots ranged from 0 to 42 percent from pellets as compared with 18 to 84 percent from nonpelleted seed.

Other tests at the same time and in the same general locality, in which the seedbed was prepared by several methods, pointed in each instance to the superiority of seeding with nonpelleted seed. From these findings, Bleak and Phillips (1950) concluded that pelleting severely reduced seed germination and field emergence.

Experiments in Oregon showed that viability of crested wheatgrass seed averaged only 25 percent when pelleted, as compared with 73 percent for nonpelleted seed (Stevenson 1949). Sixty-six percent of the viable seed incorporated into pellets failed to germinate. Field seedlings near Baker, Oregon, revealed that clay pellets disintegrated rapidly on an uncultivated seedbed, leaving many seeds exposed on the ground surface. The average numbers of seedlings per square foot on cultivated and noncultivated seedbeds on a burned-over sagebrush range where seeds had been planted by different methods at a rate of 2 pounds per acre were as follows:

	Cultivated	Noncultivated
Broadcast:		
Nonpelleted seed	0.325	0.075
Pelleted seed	.100	.050
Drilled:		
Nonpelleted seed	1.025	.850

Seedlings were significantly more numerous where seed had been drilled, but differences between stands obtained by broadcasting pelleted and nonpelleted seed, and between stands on cultivated and noncultivated seedbeds, were nonsignificant.

After evaluating results from 16 large-scale seedings and other known tests with pelleted seed from 1946 to 1961 in the western United States, Hull and other workers (1963) concluded that pelleted seed has no advantage over nonpelleted seed insofar as grass establishment is concerned.

Suitability of pellets for range revegetation was further studied by the University of Arizona from 1960 to 1963 in three vegetation types at four field locations:[4]

Semidesert shrub—Congress and Cordes
Semidesert grassland—Safford
Big sagebrush—Fredonia

Conclusions from their report, based on comparative seedings of pelleted and nonpelleted seed, were as follows:

1. Earthen-pelleted seed was not effective for seeding rangelands in Arizona. The response from pellet seeding was very poor, whether pellets were broadcast or drilled. Furthermore, method of seedbed preparation did not influence appreciably the number of plants that developed from pelleted seed.
2. The response from pelleted seed was uniformly poor under the broad spectrum of climatic and edaphic conditions near Cordes, Congress, Safford, and Fredonia, Arizona.
3. Conventional methods of range seeding with nonpelleted seed were much more effective than aerial broadcasting of pelleted seed.
4. The pelleting process commonly reduced seed germination, particularly that of large seed.

Purpose, Objectives, Organization and Scope of Investigations

This report summarizes results of research from July 1963 through June 1965 to evaluate the suitability of compressed earthen pellets for seeding rangelands. Primary objectives were:

1. To determine characteristics and properties of compressed earthen pellets.
2. To improve, through use of coatings or additives, the properties and usefulness of pellets for range seeding.
3. To determine results and costs of seeding with pellets and compare these with results and costs of seeding by methods usually used.

Laboratory and greenhouse tests were conducted at Tempe, Arizona. These tests were made both by the U. S. Forest Service and by Arizona State University under agreement with the Forest Service. Some of the seed germination tests were made and certified by the Agricultural Seed Laboratories of Phoenix, Arizona. National Forests provided land, land treatment, and assistance for some of the field plot trials and aerial seedings. Pellets were manufactured under contract by the Universal Pellet Company, Tucson, Arizona.[5]

The following studies of compressed earthen pellets were conducted at several locations in Arizona, New Mexico, and Colorado during a 2-year period:

Laboratory and greenhouse studies to determine:

1. Physical properties of pellets, including their durability under variable rainfall and temperature.

[4] *Unpublished report entitled "A terminal report on pelleted vs. non-pelleted seeds for seeding rangelands in Arizona," on file at the Department of Watershed Management, University of Arizona, Tucson.*

[5] *Patent for the pellet-making machine is owned by Dr. Lytle S. Adams, Universal Pellet Company, Tucson, Arizona.*

2. Viability, number per pound, and condition of pelleted seed.
3. Seedling emergence and development.
4. Effects of coatings and additives.
5. Rodent acceptability.
6. Effectiveness of pellets as carriers of legume inoculant.

Field plot tests to extend results of laboratory and greenhouse tests to field conditions:
1. Seeding a burned-over chaparral site in central Arizona (a) immediately after burning brush in the fall, and (b) just before the summer rainy season.
2. Interseeding mountain grassland in western Colorado with a legume, through use of inoculated pellets.

Aerial seedings to compare results of pellet seeding with those of other commonly used seeding methods at the following locations:
1. Tres Piedras (depleted sagebrush range in northern New Mexico).
2. Chacon-Luna (burned-over spruce forest in northern New Mexico).
3. Santa Rita Experimental Range (desert grass-shrub type in southern Arizona).

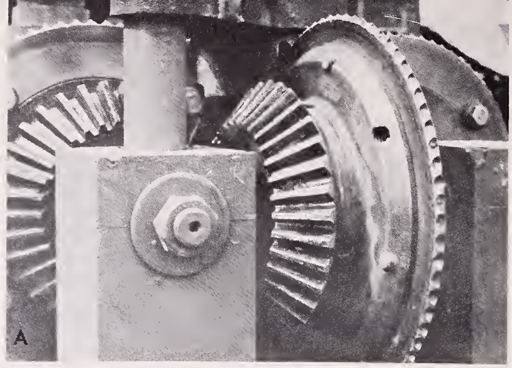
Properties of Compressed Earthen Pellets

The Pellet

Pellets used in research reported here, except those referred to as "modified" pellets, contained only soil and seed. They were of the compressed earthen type, a term commonly used to distinguish them from coated or extruded pellets. Orders for large lots of pellets generally specified only the quantity and size of pellets desired, and the kind and quantity of seed to be pelleted. Seed for pelleting was furnished by the Forest Service. Except for these limitations, pellets were tested as manufactured. Material for numerous small experimental lots of pellets was premixed in the laboratory. The manufacturer later made pellets from that material.

Compressed earthen pellets are made by a patented[5 6] machine with four gearlike wheels. The four wheels, which support a series of quarter-spherical dies along their peripheries, meet at a common point and compress a mixture of soil and seed into a round pellet. The pellets normally display four ribs formed during the manufacturing process (fig. 1).

[6] *Trade names and company names are used for the benefit of the reader, and do not imply endorsement or preferential treatment by the U. S. Department of Agriculture.*



A

Figure 1.--Compressed earthen pellets were made by feeding a mixture of seed and premoistened soil through the juncture of four vertical, revolving wheels. Quarter-spherical dies along edges of the wheels (A) meet at a common point to form a pellet. The pellets (B) normally display four ribs formed during manufacture.

B

Pellet Size and Number Per Pound

Size of pellet is governed by the size of die used. In this study, pellets 1/4 inch, 5/16 inch, and 3/8 inch in diameter were used (fig. 2). The small pellets generally proved satisfactory for very small seed, the larger ones were more suitable for large seed.

Number of pellets per pound varied not only with size of pellet but with the amount of extraneous material present. Pellets 1/4 inch in diameter averaged 1,305 per pound after being screened to remove broken particles, as compared with 1,040 per pound unscreened. Pellets 5/16 inch in diameter, in which seed of 10 species of grass or clover were separately encased, ranged in number from 479 to 703 per pound unscreened as shown below:

	Pellets (Number per pound)
Orchardgrass	703
Ranger alfalfa	695
Wilman lovegrass	665
Russian wildrye	631
Boer lovegrass	609
Timothy	607
Lehmann lovegrass	602
Medium red clover	579
Crested wheatgrass	537
Lincoln smooth brome	479

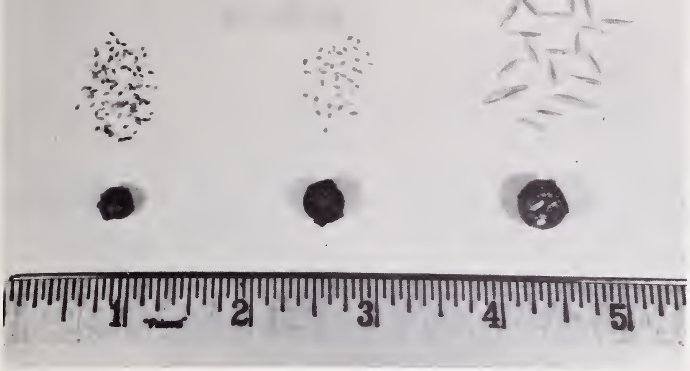


Figure 2.--Three sizes of pellet were included in various tests. Shown are a 1/4-inch pellet with weeping lovegrass seed; a 5/16-inch pellet with timothy seed; and a 3/8-inch pellet with Amur intermediate wheatgrass seed.

Screened 3/8-inch pellets of intermediate wheatgrass averaged 435 per pound and those of weeping lovegrass 506 per pound.

Pellet Composition

The soil from which pellets were made was largely clay and silt:

	Sand	Silt	Clay
	- -(Percent)- -		
Sample number:			
1	0.88	23.84	75.28
2	.49	29.61	69.90
3	9.62	27.91	62.47
4	3.82	27.19	68.99

Sample 1 was composed of hard pellets; sample 2 was a composite of pellets that crumbled when tightly squeezed between thumb and forefinger. Both samples were from the same lot of pellets. Similarity in composition of these two samples, especially in sand content, indicates that some factor other than texture probably was responsible for the difference in hardness of the pellets. Pellets in the other two samples were hard, even though their sand content was relatively high. They were made at a different time but from the same soil source used for the first two samples.

Moisture Content of Fresh Pellets

Moisture content of newly made pellets ranged from 7 to 10 percent as determined from samples of six different lots. Hardness of pellets apparently was unrelated to moisture content within that range. Soft and crumbly pellets contained 8 to 9 percent moisture; while relatively hard ones contained from 7 to 10 percent moisture.

Viability of Pellets

Viability of pellets was tested soon after they were manufactured, and 3, 6, and 12 months later. Seed used in pellets were from species commonly used in range seeding; they varied widely in size and hardness. Viability was determined in the laboratory for 50-pellet samples placed in petri dishes on moist blotters (fig. 3). Pellets that produced one or more seedlings were classed as viable.

Viability of Newly Made Pellets

Viability of pellets when manufactured ranged from 2 to 100 percent (table 1). Of the 16 species tested, nine displayed pellet viability of 70 to 100 percent; three averaged between 50 and 69 percent; and four species were less than 50 percent viable. Initial viability of three lots of alsike clover and two lots of timothy pellets was consistently higher than 90 percent; two lots each of Lincoln smooth brome and Turkestan bluestem did not exceed 11 percent. Viability of pellets of most other species varied widely from one lot to another. Results of all certified tests of seed and pellet viability are given in table 2.

The reason for the relatively wide variation in initial viability of pellets from one lot to another is not known. Considerable variation was evident among pellet lots that contained very small seed, such as those of Lehmann lovegrass, as well as those with large seed, such as intermediate wheatgrass.

Figure 3.--Viability of pellets was determined in the laboratory for 50-pellet samples placed in petri dishes on moist blotters. Pellets that produced one or more seedlings were classed as viable.

Table 1.--Viability of pellets when manufactured, and 3, 6, and 12 months later[1]

Species	Pellet lot number	Viability: When manufactured	Months after manufacture: 3	6	12
		- - - - Percent - - - -			
Alsike clover	1	93	90	98	87
Amur intermediate wheatgrass	1	3	--	--	--
Amur intermediate wheatgrass	2	91	32	26	31
Boer lovegrass[2]	1	96	99	2	0
Boer lovegrass	2	50	53	4	--
Indian ricegrass	1	23	5	4	1
Lehmann lovegrass[2]	1	72	84	30	19
Lehmann lovegrass	2	48	33	4	--
Lincoln smooth brome	1	11	--	6	4
Lincoln smooth brome	2	5	1	--	0
Medium red clover[2]	1	46	21	3	--
Medium red clover	2	100	100	100	99
Orchardgrass[2]	1	54	35	15	--
Orchardgrass	2	30	28	28	23
Range alfalfa[2]	1	79	41	8	4
Ranger alfalfa	3	78	73	41	49
Russian wildrye[2]	1	78	60	0	0
Russian wildrye	2	41	8	11	0
Standard crested wheatgrass[2]	1	58	24	9	27
Standard crested wheatgrass	2	66	52	60	56
Timothy[2]	1	95	92	0	--
Timothy	2	94	97	97	97
Turkestan bluestem	1	8	2	2	4
Turkestan bluestem	2	2	0	0	--
Weeping lovegrass	1	56	62	60	22
Weeping lovegrass	2	96	92	--	62
Wilman lovegrass[2]	1	63	75	34	3
Yellow sweetclover	1	24	7	5	5

[1]Temperature and light conditions under which these tests were made followed those specified by the Association of Official Seed Analysts (1960) and U. S. Department of Agriculture Manual for Testing Agricultural and Vegetable Seeds (1952).
[2]Pellets were not air-dried prior to storage in closed metal containers.

Change in Viability With Time

Pellets of alsike clover, medium red clover, and timothy, air-dried prior to storage, were 87 to 99 percent viable when 1 year old. Similarly dried pellets of orchardgrass and crested wheatgrass decreased in viability by only 7 and 10 percent during the year following manufacture, even though their initial viability was relatively low. Viability of other pellets included in these tests, except those of weeping lovegrass, decreased substantially during the first 3 to 6 months, whether they were air-dried or not prior to storage (table 1).

Viability as Affected by Moisture and Storage Conditions

Undried pellets placed in closed metal containers immediately after manufacture and stored in open shade for 2 weeks, during which time daytime temperatures commonly approached or exceeded 100° F., decreased sharply in viability within 3 to 6 months. Russian wildrye and timothy pellets became completely nonviable during that time. Viability of Boer lovegrass, medium red clover, Ranger alfalfa, and standard crested wheatgrass pellets decreased to 9 percent or less. None of the undried pellets displayed viability higher than 34 percent at the end of 6 months (table 1).

Further evidence of the need to reduce moisture content of pellets below a critical level is shown by differences in viability of pellets stored in paper bags and in metal containers. Viability of pellets stored in kraft paper bags averaged 41 percent and their moisture content averaged 5.6 percent at the end of 12 months. In contrast, viability of pellets placed in closed metal containers before they had become air-dry averaged 8.7 percent at the end of 6 months, and their moisture content averaged 8.8 percent. Though relatively small, the difference in moisture content evidently was sufficient to alter pellet viability appreciably.

	Viability (Percent)	Moisture (Percent)
In metal containers:		
Boer lovegrass	2.0	8.8
Lehmann lovegrass	30.0	8.1
Medium red clover	3.2	7.0
Ranger alfalfa	8.2	9.9
Timothy	0.0	10.1
In paper bags:		
Boer lovegrass	48.0	5.7
Lehmann lovegrass	19.0	5.9
Medium red clover	13.5	5.4
Ranger alfalfa	40.0	5.5
Timothy	85.0	5.7

Table 2.--Summary of certified germination tests[1]

Species	Seed to be used in pellets					Pellets				Average number seedlings per viable pellet
	Seed lot	Date tested	Germi- nation	Hard seed	Viable seed	Pellet lot	Date made	Date tested	Viable pellets	
			- - Percent - -						Percent	
Alsike clover	CA1710	6/10/64	81	6	87	1	5/64	6/10/64	93	3.3
	RN	6/21/65	85	6	91	2	4/65	6/21/65	94	5.1
	RN	6/21/65	83	3	86	3	6/65	6/21/65	96	4.8
Amur intermediate wheatgrass	D2-618	9/4/63	91	0	91	1	8/63	9/20/63	3	1.0
						2	2/64	4/28/64	91	2.4
Boer lovegrass	V2800	9/11/63	83	6	89	1	8/63	9/13/63	96	4.6
	V2800	6/2/64	86	4	90	2	6/64	7/8/64	50	1.3
	V2800	3/3/65	86	6	92	3	5/65	5/20/65	44	1.4
						4	6/65	7/21/65	88	--
Indian ricegrass	A	12/30/63	0	63	63	1	12/63	3/10/64	23	1.0
Lehmann lovegrass	V2804	9/11/63	71	20	91	1	8/63	9/63	72	4.5
	V2804	6/11/64	83	11	94	2	5/64	6/11/64	7	1.5
						2	5/64	6/64	48	1.5
	V2804	3/11/65	82	10	92	3	5/65	5/20/65	50	2.1
						3	5/65	7/21/65	64	--
						4	6/65	7/21/65	77	--
Lincoln smooth brome	ZL20051N	8/26/63	69	0	69	1	8/63	9/8/63	11	1.1
						2	9/63	9/27/63	5	1.0
Medium red clover	RC101BG	8/14/63	80	2	82	1	8/63	8/20/63	46	1.8
						1	8/63	3/64	6	[2]1.1
						2	10/63	10/29/63	94	5.2
Orchardgrass	F31327	8/28/63	84	0	84	1	8/63	9/3/63	54	1.7
	H04140W	10/29/63	74	0	74	2	10/63	11/28/63	30	1.2
		1/30/64	80	0	80	2	10/63	1/30/64	33	1.2
Ranger alfalfa	W210W	8/14/63	90	0	90	1	8/63	8/29/63	79	2.4
						1	8/63	3/16/64	10	[2]1.1
						2	10/63	10/29/63	60	2.3
						3	11/63	12/9/63	78	2.7
Russian wildrye	R2-719	8/26/63	88	0	88	1	8/63	9/1/63	78	2.1
						1	8/63	3/64	0	[2] --
						2	10/63	11/5/63	41	1.4
Standard crested wheatgrass	W190	8/28/63	86	0	86	1	8/63	9/3/63	58	1.8
						1	8/63	4/2/64	12	[2]1.2
	62X100	10/4/63	80	0	80	2	10/63	10/22/63	66	1.8
						2	10/63	11/21/63	60	1.5
Timothy	T35353	8/22/63	83	0	83	1	8/63	8/28/63	95	3.4
						1	8/63	4/2/64	0	[2] --
	T45323	10/18/65	85	0	85	2	10/63	11/1/63	94	7.8
						2	10/63	11/17/63	97	7.5
Turkestan bluestem	4333	1/15/64	85	0	85	1	11/63	12/30/63	8	1.0
						2	2/64	7/24/64	0	--
Weeping lovegrass	P3242	8/21/63	69	4	73	1	8/63	9/6/63	56	3.5
						2	11/63	12/16/63	96	5.4
Wilman lovegrass	P3510#2	9/11/63	67	9	76	1	8/63	9/63	63	2.6
Yellow sweetclover	CZ2004-M	8/14/63	51	10	61	1	9/63	9/20/63	24	1.1

[1]Temperature and light conditions under which these tests were made followed those specified by the Association of Official Seed Analysts (1960) and U. S. Department of Agriculture Manual for Testing Agricultural and Vegetable Seeds (1952).
[2]Pellets were not air-dried prior to storage in closed containers.

In other tests, medium red clover pellets retained viability of 99 to 100 percent for 1 year, whether air-dried at room temperature or ovendried at 38° C. (100° F.) for 24 hours following manufacture. Drying at 100° C. (212° F.) for 24 hours, however, reduced viability of newly made pellets to 18 percent. Seed of Lincoln smooth brome, Russian wildrye, and Turkestan bluestem evidently was more readily damaged by excess moisture in the pellet than was seed of other species.

The conclusion from these tests was that pellets should be air-dried soon after manufacture to prevent or reduce damage to seed from moisture in the earthen matrix. If the seed is particularly susceptible to damage from excess moisture, or if pellets are made under humid conditions, artificial drying to a moisture content of 5 percent or less may be necessary.

In these studies large quantities of pellets used for field plantings were spread over a plastic-lined concrete floor to a depth of 3 inches and allowed to dry 2 or 3 weeks in the warm, dry climate before being stored in plastic bags. This drying method proved satisfactory.

Though the relation of temperature to pellet viability was not investigated, available evidence indicates that ample ventilation should be provided if ambient temperatures in the storage area are expected to exceed 90° F.

Characteristics of Pelleted Seed

Seeds were extracted from pellets, counted, classified, and tested for viability to determine the proportion of pellets that contained seed, how many seeds were present in individual pellets, and how pelleting affected soundness and viability of seed.

Number of Seeds per Pellet

The number of seeds in a given lot of pellets was governed primarily by the amount of seed used in pellet manufacture. The number present in individual pellets, however, varied with the amount of seed used, size of pellet, and ability of the manufacturer to mix seed and soil uniformly. Sufficient seed was furnished in most instances to provide 50 to 15 seeds per pellet.

Extraction of seed from eight lots of pellets revealed an average of 3.8 seeds per pellet (table 3); 90 percent of those pellets contained one or more seeds. The percentage of pellets with seed was, in general, inversely related to size of seed. Small seeds apparently were mixed more uniformly with the earthen matrix than were large ones.

Table 3.--Average number and apparent condition of seeds within pellets, and germination of seed extracted from pellets

Species[1]	Pellets with seed	Average seeds per pellet			Germination of seeds extracted from pellets		Not pelleted
		Apparently sound	Apparently unsound	Total	Apparently sound	Apparently unsound	
	Percent	- - - - Number - - - -			Percent		
Lehmann lovegrass	99	([2])	([2])	5.9	([2])	([2])	([2])
Turkestan bluestem	95	1.6	1.6	3.2	19	0	85
Indian ricegrass	99	4.8	1.1	5.9	0	0	0
Orchardgrass Lot 1	93	2.0	2.4	4.4	24	10	84
Lot 2	89	1.5	1.2	2.7	18	1	74
Crested wheatgrass Lot 1	90	2.2	.9	3.1	9	0	86
Lot 2	79	2.2	.5	2.7	33	5	80
Russian wildrye	75	1.2	.9	2.1	18	2	88
Average	90	2.2	1.2	3.8	17.3	2.6	71

[1]Listed in order of increasing seed length. Lehmann lovegrass extracted from 1/4-inch diameter pellets. Other species from 5/16-inch diameter pellets.
[2]Seeds were too small to determine their soundness.

Viability of Extracted Seed

About two-thirds of the seeds extracted from pellets were unbroken and appeared sound. Germination of seed that appeared to be sound averaged 17 percent compared with 71 percent for seed from the same lots that had not been pelleted (table 3). Such difference suggests unseen damage during manufacture. Seed of Indian ricegrass that appeared to be sound failed to germinate whether or not it had been pelleted, a common experience with the species. Seed of all species that appeared to be unsound when extracted from the pellet averaged only about 3 percent germination.

Mixing and pelleting the relatively light and large seed of Lincoln smooth brome was difficult. Consequently, only 22 percent of the pellets examined contained seed. The number of seeds extracted from them was inadequate for a reliable test of viability.

Seedling Emergence and Development in the Laboratory

The ability of seedlings to emerge from pellets and to develop strong root systems was evaluated in conjunction with germination tests and through observation of seedling development in the greenhouse. In the latter tests, pellets were placed on sand in flats and subjected to various amounts of artificial rainfall at varied intervals. Artificial rain was produced by attaching the applicator of a Rocky Mountain infiltrometer (Dortignac 1951) to a hydrant. Intensity and frequency of rainfall applied in a given test were governed by the objective of that test: to maintain a moisture level suitable for seed germination, or to determine behavior of pellets and seedlings under different rainfall applications. Following each application of rainfall, pellets were classified according to degree of melt; seedlings were classed as strongly or weakly rooted, and seedling heights were measured.

Seedling Emergence

The number of seedlings that emerged from earthen pellets in certified germination tests averaged 2.5 per viable pellet. Included in those tests were the 16 species of plants listed in table 1. Average number of seedlings per pellet varied from 1.0 to 7.8; the variation among pellet lots of a given species was about the same as that among species. Occasionally 10 or more seedlings emerged from a single pellet. Seedling emergence from all pellets included in certified tests is recorded in table 2.

In greenhouse tests, seedlings usually began to emerge 5 to 7 days after pellets were moistened by artificial rainfall. Seedlings averaged 3.1 per viable pellet for all tests, and varied from 1.1 to 4.9 among individual tests. Pellets containing weeping lovegrass seed were used in 18 of the 20 tests conducted.

Seedling Development

Development of seedlings from earthen pellets was influenced by several factors, one of the most obvious being the amount of pellet material that remained to support the young plants after they were sprinkled with artificial rain (table 4). Seedlings developed best when the pellet material remained around the roots. Such plants were classified as strongly rooted. When the rain washed supporting pellet material completely away from the seedling's roots, it usually toppled and died. When only part of the root system was exposed, the seedling commonly survived but developed slowly. Under the latter two situations, seedlings were classified as weakly rooted.

Pellets moistened with small amounts of artificial rain applied at low intensity disintegrated less readily than those which received rainfall in larger amounts or at higher intensities. Under 1-inch applications, the identity of individual pellets was lost before the number of seedlings per pellet could be determined.

Seedlings of some species apparently were better able than others to develop from pellets. In one test, for example, only 27 percent of the seedlings of Ranger alfalfa were strongly rooted when 6 days old, compared to 70 percent for weeping lovegrass and 100 percent for timothy seedlings (table 4). The second weekly application of 0.28 inch of artificial rain applied at a rate of 5 inches per hour caused most melting of pellets and damage to seedlings.

In subsequent tests in which rain was applied in variable amounts and at different intervals to pellets containing weeping lovegrass seed, 67 to 99 percent of the seedlings were strongly rooted. Strongly rooted plants were consistently taller than those weakly rooted. One-quarter inch of rain applied 2 days apart produced taller seedlings than a comparable amount applied 4 days apart. Although 1-inch applications of rain disintegrated pellets more rapidly than did smaller amounts, they evidently did not appreciably retard seedling development.

Durability of Pellets and Development of Seedlings in the Field

To determine how pellets and seedlings that developed from them under field conditions were affected by weather, rodents, and kind of seedbed, pellets were hand placed in local areas on a sagebrush site near Tres Piedras, New

Table 4.--Emergence and development of seedlings from earthen pellets in the greenhouse under varied applications of simulated rainfall, 1964

Species	Emergence of seedlings		Development of seedlings				Age of seedlings (time since initial emergence)
	Per pellet	Total	Proportion		Height		
			Strongly rooted	Weakly rooted	Strongly rooted	Weakly rooted	
	Number		Percent		Inches		Days
Rainfall - Two applications of 0.28 inch 1 week apart 5/5 - 5/12/64. Pellets 5/16-inch							
Ranger alfalfa	1.1	22	27	73	0.9	0.3	6
Weeping lovegrass	2.8	68	70	30	.7	.4	6
Timothy	2.1	87	100	0	.6	--	6
Rainfall - 21 applications of 0.25 inch 2 days apart (10/7 - 11/23/64). Pellets 3/8-inch							
Weeping lovegrass	3.8	190	79	21	3.0	1.2	43
Do.	4.9	231	82	18	3.2	1.4	43
Do.	4.6	230	86	14	3.1	1.2	43
Do.	4.3	212	88	12	3.1	1.0	43
Do.	2.8	154	76	24	2.4	1.1	43
Rainfall - 17 applications of 0.25 inch 4 days apart (10/22 - 12/18/64). Pellets 3/8-inch							
Weeping lovegrass	2.4	97	79	21	2.8	1.2	55
Do.	2.1	85	67	33	2.3	1.1	55
Do.	2.7	90	72	28	2.4	1.3	55
Do.	3.2	113	73	27	2.3	1.1	55
Do.	3.4	144	88	12	2.4	1.2	55
Rainfall - 8 applications of 1.0 inch 2 days apart (12/2 - 12/21/64). Pellets 5/16-inch, handmade							
Weeping lovegrass	--	177	99	1	.6	.4	14
Do.	--	189	97	3	.5	.2	14
Rainfall - 7 applications of 1.0 inch 2 days apart (12/4 - 12/21/64). Pellets 3/8-inch							
Weeping lovegrass	--	199	69	31	.5	.2	10
Do.	--	249	72	28	.5	.2	10
Do.	--	223	78	22	.5	.2	10
Do.	--	184	94	6	.5	.4	10
Do.	--	208	67	33	.5	.2	10

Mexico (fig. 4), on a burned-over chaparral site at Brushy Basin in central Arizona, and on a semidesert shrub site on the Santa Rita Experimental Range in southern Arizona.

Response in Sagebrush Type

At Tres Piedras, twelve 50-pellet samples of 5/16-inch pellets containing crested wheatgrass were set out in October 1963. Of these, six were protected from rodents by hardware-cloth cages. Within each group, three were on plowed ground and three were on unplowed ground. Sixteen days after being set out, and following 0.69 inch of precipitation, 89 percent of the pellets had melted little if at all, and only 11 percent were more than half melted. Sixteeen percent were deeply fractured or broken.

The following April, remains of 86 to 96 percent of the pellets were visible on areas not plowed, compared with 28 to 57 percent on areas that had been plowed prior to seeding. Though 12 to 22 percent of the pellets on unplowed land were evident as low mounds, other pellet remains consisted only of darkened areas. Overwinter precipitation totaled 3.84 inches, most of which was snow.

Seeds of crested wheatgrass were exposed on the ground surface of all plots. Exposed seeds within cages, however, were about five times as numerous as those in the open.

The number of seedlings from each group of 150 pellets, as observed in October 1964 and August 1965 on plowed and unplowed seedbeds, was as follows:

	October 1964	August 1965
Inside cages:		
Plowed	30	22
Unplowed	16	1
Outside cages:		
Plowed	3	3
Unplowed	3	0

Figure 4.--Pellet durability tests.

Wire cages were placed over certain pellet groups to prevent possible depredation by rodents.

Location of individual pellets was marked with toothpicks.

In October 1964, one seedling was present for every five pellets that had been placed there. More than half the seedlings observed at that time were very small. By August 1965, few plants had survived except those inside the cages on plowed ground, but surviving plants appeared to be well established.

Response in Burned-Over Chaparral

To test pellet durability and seedling development in burned-over chaparral, 1,800 earthen pellets were set out February 11, 1964, and an equal number on July 2, near Brushy Basin in central Arizona. The experimental area had been burned the preceding fall to remove the brush. On both dates, three clusters of 100 pellets each of weeping lovegrass, Ranger alfalfa, and Turkestan bluestem were placed inside hardware-cloth cages similar to those used at Tres Piedras; similar clusters were placed outside the cages. Pellets were 5/16 inch in diameter.

One month after the February planting, 11 percent of the pellets were essentially intact, 68 percent had partly melted, and 21 percent had melted almost completely. After 2 months, one-third were still partly intact, but by the end of the third month all had melted completely. Pellets set out July 2 were melted completely within 2 weeks by 1.6 inches of rain.

Though few seedlings from either test emerged prior to July 15, emergence was rapid during the following 2 weeks. On July 28, the following numbers of seedlings were present:

	Set out February 11	Set out July 2
Inside cages:		
Weeping lovegrass	77	122
Ranger alfalfa	10	2
Turkestan bluestem	1	10
Outside cages:		
Weeping lovegrass	53	24
Ranger alfalfa	2	3
Turkestan bluestem	2	6

Weeping lovegrass produced by far the most seedlings in these tests. In the July 2 planting, one seedling of lovegrass emerged for every two and one-half pellets placed inside the cages. As at Tres Piedras, seedlings were more numerous inside the cages than outside. In laboratory tests, viability of Turkestan bluestem pellets was low, so the poor showing in the field was not unexpected; however, the near failure experienced with Ranger alfalfa cannot be explained.

Response in a Semidesert Grass-Shrub Type

On the Santa Rita Experimental Range in southern Arizona, 1,200 pellets 1/4 inch in diameter were set out July 9, 1964, on a semidesert grass-shrub site that had been sprayed previously with herbicide to control mesquite. Little vegetation was present on the test plots at time of seeding. Included in the test were six groups of 100 pellets each of Boer lovegrass and Lehmann lovegrass. Again, half the pellets were inside and half were outside rodentproof cages.

Twelve days after the pellets had been set out, during which time 0.74 inch of rain fell, one-third of the pellets were essentially intact. Within 1 month, however, and following additional rainfall of 2.95 inches, all pellets had melted completely.

The numbers of seedlings present August 4 and August 19, 1964, are shown below:

	August 4	August 19
Inside cages:		
Lehmann lovegrass	23	3
Boer lovegrass	29	2
Outside cages:		
Lehmann lovegrass	45	15
Boer lovegrass	21	9

Within the first month after pellets were set out, one seedling had emerged for every six pellets of Lehmann lovegrass located outside the cages. In this test, cages provided no benefit. All seedlings had died or were taken by ants before plots were next observed September 21, 1964. Reason for the high mortality is not known. Rainfall totaled 5.05 inches during August and 5.00 inches from September 1 to 21.

Laboratory Tests of Pellet Durability

It was observed that the pellets usually disintegrated within a relatively short time in the field leaving the seed exposed on the ground surface. Consequently, two of the more important possible benefits from pelleting were almost lost: protection of seed from depredation, and provision of a more favorable environment for seed germination and seedling development. To learn more specifically the cause and nature of pellet breakdown, pellets were exposed to artificial rain in varying amounts and intensities and subjected to freeze-thaw tests in the laboratory.

Artificial rain was applied with equipment from a Rocky Mountain infiltrometer described by Dortignac (1951). Rainfall intensities under natural conditions commonly are 1 to 3 inches per hour, but during cloudbursts they may approach or exceed 5 inches an hour. Goals were to apply artificial rain at rates of 1, 3, and 5 inches an hour, but actual average intensities for each of those rates varied because of fluctuating water pressure (table 5).

Earthen pellets used in these tests were placed on three substrates: (1) a clay soil that drained slowly; (2) decomposed leaf litter that drained rapidly; and (3) window screen on which pellets were wet only by falling drops of water. Those substrates were selected to represent the wide range in conditions that might be encountered in the field.

Table 5.--Percentage of earthen pellets completely melted on clay, litter, and screen substrata by artificial rain during periods indicated

Substrata and rain intensity (Inches per hour)	Time lapse	Rain applied	Pellets melted
	Minutes	Inches	Percent
CLAY:			
2.07	4	0.14	18
	8	.28	45
	12	.43	72
	16	.56	83
	20	.69	100
3.04	2	.10	12
	4	.20	43
	6	.31	73
	8	.41	89
	10	.51	100
5.31	2.5	.21	58
	5.0	.43	82
	7.5	.65	90
	10.0	.88	96
	12.5	1.10	100
LITTER:			
1.52	10	.25	0
	20	.50	5
	30	.76	15
	40	1.02	37
	50	1.27	100
2.44	5	.18	2
	10	.40	16
	15	.60	36
	20	.82	61
	25	1.01	100
5.23	2	.15	2
	4	.34	22
	6	.52	42
	8	.70	69
	10	.87	100
SCREEN:			
1.80	7	0.22	0
	14	.46	41
	21	.68	77
	28	.87	93
	35	1.06	100
2.98	5	.24	0
	10	.50	27
	15	.74	76
	20	1.01	95
	25	1.26	100
4.85	3	.22	0
	6	.48	20
	9	.72	64
	12	.97	90
	15	1.22	100

Pellet Breakdown Under Simulated Rainfall

The rate at which earthen pellets melted under artificial rain varied both with intensity of rainfall and with the kind of surface on which the pellets lay. As little as one-half inch of rainfall, when applied at an intensity of 3.04 inches an hour, resulted in complete disintegration of pellets on clay soil (table 5). Ponding of water on the

clay surface sufficiently deep to cover pellets retarded melting.

Pellets underlain with 3 inches of coarsely pulverized leaf litter usually disintegrated more slowly than those on clay soil. When suspended on window screen, pellets remained partly intact until as much as 1.26 inches of rain had been applied.

During these tests, surface cracks formed soon after pellets became wet. Disintegration then generally increased in proportion to the rate and amount of rainfall applied. Relatively few pellets melted completely under less than one-fourth inch of rainfall, but practically all were destroyed by an inch or more of rain.

Effect of Freezing and Thawing

Alternate freezing and thawing as a possible cause of pellet breakdown was studied with pellets containing seed of crested wheatgrass, a large-seeded species, and Lehmann lovegrass, a small-seeded species. Pellets were subjected to 10 freeze-thaw cycles over a 2-week period. Prior to being frozen, 100 pellets of each species were moistened and 100 were left dry.

Alternate freezing and thawing had no visible effect on any of the dry pellets; it caused only minor sloughing of particles from three pellets that had been moistened.

Effectiveness of the Pellet as a Rodent Deterrent

The effectiveness of earthen pellets in protecting seed against depredation by rodents was tested by offering pellets containing seed of three grass species to caged deer mice (Peromyscus), in the Denver Wildlife Research Laboratory.[7] Deer mice are one of the more important seed-eating rodents in the western United States. In preliminary tests, deer mice apparently preferred Lehmann lovegrass, orchardgrass, and intermediate wheatgrass seed to seed of 10 other grasses and clovers. Therefore, these species were used in the test.

Offered as the only food source, pellets containing seed of Lehmann lovegrass were undamaged by mice during three 24-hour periods. Under similar conditions, 70 percent of the pellets with orchardgrass seed and 52 percent of those with intermediate wheatgrass seed were undamaged.

When pelleted seeds of those grasses were offered along with a supplement of rodent food, 97, 65, and 84 percent, respectively, of the total number of pellets furnished were undamaged. In both instances, pellets that contained relatively large seeds, parts of which commonly were exposed, were damaged more extensively than pellets with small seeds.

These tests indicate that pelleting may greatly reduce loss of grass seed to deer mice in range seedings if the pellets remain intact until conditions are favorable for seed germination.

Modification of Clay Pellets

Compressed earthen pellets melt readily, thereby exposing seed or weakly rooted seedlings to rapid drying and depredation. The primary purpose of modifying pellets, therefore, was to increase their durability without lowering viability. Other goals were to reduce weight of the pellet and to improve its ability to absorb and retain water. Reduction in pellet weight would reduce cost of aerial distribution. Improvement in water-absorbing and water-retaining properties might aid seed germination and enhance seedling development and survival. Some pellets were modified by coatings, others by additives.

Coatings

Three pellet coatings were tested: Latex 512-R, Latex 122-A20, and methocel (Methyl cellulose). All are products of Dow Chemical Company. Behavior of coated pellets and development of seedlings from them were compared with that of regular pellets by applying artificial rain in amounts of 1/4 inch at 2-, 4- or 7-day intervals. The amount of continuous rain required to melt pellets completely was also measured.

Though all coatings tested retarded melting, Latex 512-R was the most satisfactory. Only 10 percent of the pellets coated with that material were melted by 1.25 inches of artificial rain and 70 percent were practically intact after 3.75 inches had been applied. A total of 18.8 inches of rain applied continuously was required to melt all pellets completely. Viability of pellets coated with Latex 512-R apparently was unaffected by the coating; it averaged 80 to 86 percent (fig. 5). Eighty-eight to 93 percent of the seedlings were strongly rooted.

Figure 5.--Pellets coated with Latex 512-R melted slowly and retained high viability. The synthetic coating permitted pellets to absorb water, and apparently did not hinder seedling emergence.

[7] *The rodent deterrent tests were made by the U. S. Bureau of Sports Fisheries and Wildlife whose assistance is gratefully acknowledged.*

Latex 122-A20 proved unsatisfactory as a coating. It was relatively tough and inelastic, and prevented absorption of water.

Methocel coatings were moderately effective in retarding pellet disintegration. In the laboratory, pellets coated with methocel continued to support most seedlings after 0.6 inch of rain had been applied (fig. 6).

Under field conditions, 22 percent of the coated pellets and 67 percent of untreated pellets were melted almost completely by 0.74 inch of rain on the Santa Rita Experimental Range. At Brushy Basin, 1.6 inches of rain completely melted all pellets, both coated and uncoated. Though pellets coated with methocel were 10 to 21 percent less viable than untreated pellets, seedlings that developed from them usually were more strongly rooted.

Additives

Gelgard, a highly absorptive substance, was mixed with pelleting clay in amounts ranging from 0.25 percent to 14 percent, and the mixture was made into pellets. Some of those pellets were then coated with Latex 512-R. Other additives included methocel in amounts of 0.25 to 10 percent, mixtures of Gelgard and methocel, starch, peat moss, and perlite. The latter two substances were tested primarily to determine their suitability for reducing pellet weight.

Effectiveness of Gelgard and methocel, both individually and mixed, in retarding pellet disintegration generally increased in proportion to the amount of those materials in the pellet. The Latex 512-R coating further increased durability of pellets containing Gelgard.

Pellets that contained 0.25 percent of Gelgard or methocel melted almost as rapidly as did unmodified pellets. Pellets with 1 percent or more methocel, however, whether or not mixed with Gelgard, retained their identity after being sprinkled with 2.75 inches of water in 0.25-inch amounts every 4 days. They also withstood 1 inch of continuous, artificial rain.

Gelgard alone was reasonably effective in retarding pellet breakdown, particularly when it comprised 2 percent or more of the pellet. Not more than a third of the pellets with that composition melted completely under 2 inches of artificial rain applied in 0.25-inch amounts. Pellets with Gelgard swelled to several times their original size upon becoming wet (fig. 7). Disintegration apparently began when the amount of water absorbed by the pellet exceeded the moisture-holding capacity of the Gelgard.

Although Gelgard pellets absorbed moisture readily, they also dried rapidly. Consequently, seedlings that developed from them may have received little if any more water than those from unmodified pellets.

Viability of pellets with Gelgard was relatively high—generally above 75 percent, but the swelling action of

Figure 6.--Pellets coated with methocel (top) resisted breakdown and supported seedlings better than did untreated pellets. On the left are weeping lovegrass seedlings emerging from pellets wet with 0.3 inch of artificial rain. On the right are the same seedlings following the second application of an equal amount of rain a week later. Note the toppled seedling on the untreated pellet (lower right). If it survived, that seedling would have been weakly rooted.

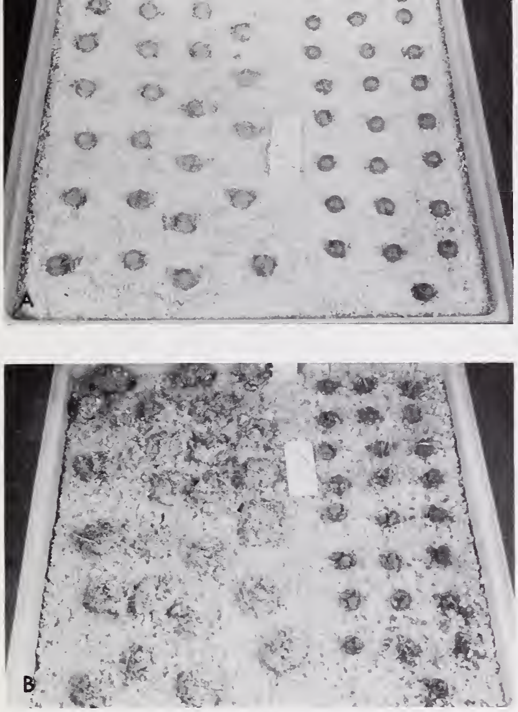


Figure 7.--Appearance of pellets with and without Gelgard (A) before, and (B) after 3.25 inches of artificial rain had been applied in amounts of 1/4 inch every 4 days. Pellets containing 14 percent Gelgard are on the left;unmodified pellets are on the right. The Gelgard pellets swelled several times their original size but none melted completely. Most unmodified pellets also held up reasonably well in these tests.

Gelgard apparently interfered with seedling development (fig. 8). For that reason, coating pellets with Latex 512-R is considered to be a more satisfactory way to increase pellet durability.

Methocel as an additive deserves further study, particularly as it affects pellet viability and seedling development. Viability of pellets and development of seedlings from pellets that contained methocel, and those that contained 5 percent or less Gelgard, was not determined because of an unfortunate loss of temperature control in the greenhouse when those pellets were being tested.

Starch, mixed with pelleting clay at a ratio of 1:20, proved effective as a binding agent but retarded seed germination and seedling emergence.

Figure 8.--Seedlings of weeping lovegrass on the left are from pellets that contained 14 percent Gelgard. Those on the right are from unmodified pellets. All are 7 weeks old.

Peat moss and perlite were about equally effective in reducing pellet weight, thereby increasing the number per pound. Pellets that contained one part peat to five or eight parts clay numbered 452 to 502 per pound, an increase of 8 to 20 percent over regular pellets. Those with perlite (1:10 mixture) numbered 482 per pound, an increase of 15 percent. Durability of both kinds of pellets was similar to that of unmodified pellets.

Special Uses for Clay Pellets

As a Carrier of Fertilizer

Potassium nitrate is known to stimulate germination of certain grass seeds, and to have some fertilizer value. To determine its effect on pellet viability and vigor of developing seedlings, it was incorporated into pellets in amounts of 0.1, 1.0, and 2.0 pounds per 100 pounds of clay. Crested wheatgrass seed was used in all pellets tested.

Viability of pellets and height of seedlings from pellets that contained 0.1 and 1.0 percent potassium nitrate were little different from those of untreated pellets. Viability of pellets with 2.0 percent potassium nitrate, however, was 12 percent lower than that of regular pellets. When 46 days old, seedlings from pellets with 2 percent nitrate averaged 4.1 inches in height as compared with 3.1 inches for seedlings from untreated pellets (fig. 9). It appears that incorporation of enough potassium nitrate to increase seedling vigor may decrease pellet viability.

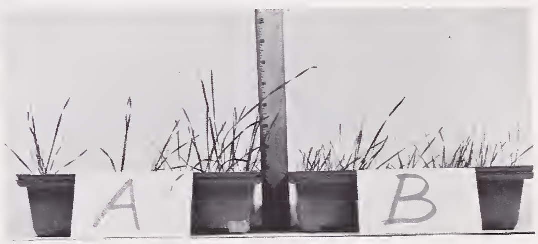


Figure 9.--Crested wheatgrass plants in tray A, grown from pellets that contained 2 percent potassium nitrate, are more vigorous than those in tray B that developed from untreated pellets. Viability of pellets containing 2 percent potassium nitrate was 12 percent lower, however, than that of pellets without fertilizer.

As a Carrier of Nitrogen-Fixing Bacteria

Nitrogen-fixing bacteria (Rhizobia) soon die when exposed to the atmosphere. Consequently, most attempts to interseed rangeland with a legume inoculated in the ordinary manner have not given satisfactory results. Hastings and Drake (1960) found in New Zealand that the life of bacteria in contact with legume seed can be extended up to 10 months by using methyl cellulose as an adhesive and coating the seed with certain phosphates and carbonates.

To test effectiveness of earthen pellets as a carrier of nitrogen-fixing bacteria, alsike clover seed was mixed with a peat-culture inoculant in a thick solution of methyl cellulose. The inoculated seed was then incorporated into 3/8-inch pellets.

In greenhouse tests conducted over an 8-month period, development of seedlings from inoculated pellets, and formation of nodules on their roots (fig. 10) was as follows:

	Viable pellets (Percent)	Seedlings per viable pellet (Number)	Viable pellets producing nodulose seedlings (Percent)
Months since inoculation:			
1	92	3.2	100
2	74	1.5	100
3	87	2.4	94
4	88	2.9	100
5	96	3.7	100
6	97	3.6	100
7	98	3.8	98
8	98	3.4	97

Nitrogen-fixing bacteria survived at least 8 months, the longest period tested, within the earthen pellets. Inoculated pellets may, therefore, provide a means for interseeding rangeland with an inoculated legume. This avenue of research deserves further study.

Results of Field Plot Tests

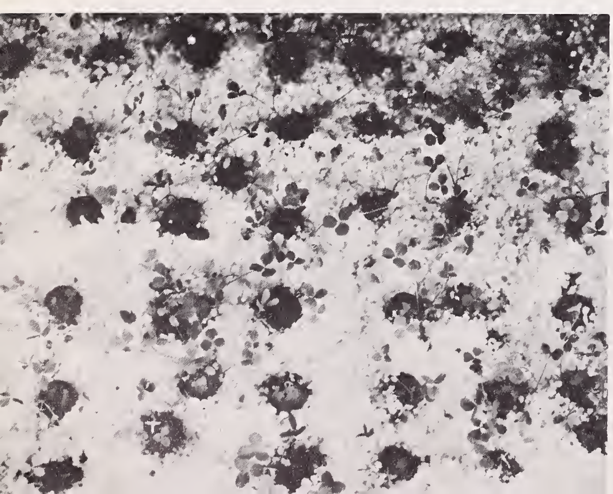
Brushy Basin Test

The Brushy Basin test was made to evaluate the pellet method on a recently burned-over chaparral range in Arizona (fig. 11). The experimental area is located at 6,000 feet elevation on the Tonto National Forest, where average annual rainfall probably exceeds 25 inches. The moderately rugged terrain, generally north facing, is underlain with coarse granitic soil. Test plots were located a short distance from a site that had been successfully seeded previously by broadcasting seed directly into the ashes. Seeding by such a method is common practice in the vicinity.

Brush on the experimental area was cabled and broadcast-burned in October 1963. A good ash seedbed resulted. The experimental plots were paired. One of each pair was seeded with pellets containing seed of weeping lovegrass, Turkestan bluestem, and Ranger alfalfa, and the other was hand-broadcast seeded with regular seed of the same species. Pellets were distributed at the rate of two per square foot. Both plots received about the same number of seeds per square foot. Half the plots were seeded November 27, 1963, a month

Figure 10.--Inoculated pellets were 98 percent viable 8 months after manufacture.

Alsike clover seedlings emerging from inoculated pellets.



Nodules on the root of a clover seedling that developed from an inoculated pellet (Magnification about 10X).

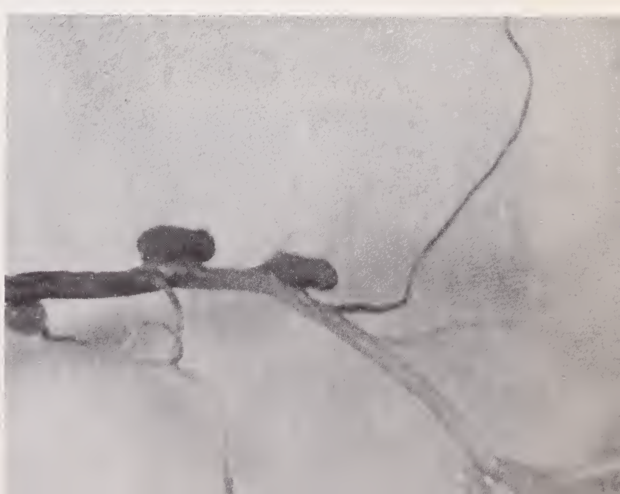


Figure 11.--This recently burned-over chaparral site near Brushy Basin in central Arizona was broadcast seeded with regular and pelleted seed of two grasses and a legume.

aft-; the burn. The others were seeded July 2, 1964, just preceding summer rains. Weeping lovegrass has been widely and successfully used in seedings of this type; Turkestan bluestem is a desirable species that had become established in nearby trials; and Ranger alfalfa is known to be adapted to local conditions.

Best stands from pellets were of weeping lovegrass seeded July 2, 1964 (table 6). Four months after pellets were distributed, plants numbered 39 per 100 square feet. This is about 40 percent of the number of established plants needed for a satisfactory stand. The best stands from the fall seeding of pellets also were of weep-

Table 6.--Abundance of seeded plants in 1964 and 1965 on burned-over chaparral land where pellets and nonpelleted seed of three species were hand broadcast in 1963 and 1964, Brushy Basin, Arizona

Seeding date, species, and treatment	Plants counted, by date					
	1964				1965	
	August 13	August 31	September 17	November 2	April 9	June 26
	Number per 100 square feet					
Seeded November 26, 1963--						
Ranger alfalfa:						
Pelleted	4	4	2	2	3	1
Nonpelleted	21	16	19	20	17	12
Turkestan bluestem:						
Pelleted	2	0	1	0	0	0
Nonpelleted	2	2	1	([1])	([1])	([1])
Weeping lovegrass:						
Pelleted	13	19	19	23	19	14
Nonpelleted	32	30	43	58	52	42
Seeded July 2, 1964--						
Ranger alfalfa:						
Pelleted	2	1	1	1	1	([1])
Nonpelleted	77	49	59	71	56	14
Turkestan bluestem:						
Pelleted	2	1	0	([1])	([1])	([1])
Nonpelleted	10	10	6	10	12	8
Weeping lovegrass:						
Pelleted	23	22	33	39	35	20
Nonpelleted	78	47	62	107	84	79

[1]Less than 1.

ing lovegrass. About one-fifth the number of plants desired was present a year after that seeding was made. Only scattered plants of Ranger alfalfa and Turkestan bluestem developed from pellet seeding.

Stands obtained by broadcasting regular seed showed that conditions were favorable on July 2 for seeding weeping lovegrass and Ranger alfalfa, but not the bluestem. The number of weeping lovegrass plants from summer seeding averaged 107 per 100 square feet on November 2, 1964, an ample stand. This had decreased to 79 plants by June 26, 1965. By the same date, the average number of weeping lovegrass seedlings from the November 1963 seeding was 42 per 100 square feet.

The largest number of Ranger alfalfa plants observed at any time on check plots seeded with regular seed averaged 77 per 100 square feet. Turkestan bluestem plants did not exceed 12 per 100 square feet, a number inadequate for a reliable comparison between methods for seeding.

The near failure of Turkestan bluestem is unexplained; viability of the seed used was 85 percent. Precipitation was ample and well distributed to give good seedling emergence and establishment. It totaled 31.6 inches from July 15, 1964 to April 19, 1965, 8.45 inches falling during the 2 months after plots were seeded. Competition from native forbs, which became abundant during the summer of 1964, might have retarded development of bluestem.

Black Mesa Tests

The purpose of field tests on Black Mesa Experimental Forest and Range on the Gunnison National Forest in western Colorado was to determine the feasibility of interseeding high mountain grasslands with a legume through use of pellets. Most efforts to interseed such rangeland with legumes have been unsuccessful, conceivably because of the difficulty in successfully inoculating the young plants with nitrogen-fixing bacteria. If continually exposed to the atmosphere, nodule-forming bacteria may die during the period from seed inoculation to seed germination.

Tests were made in 1964 and 1965. The sites selected for seeding were on weedy mountain grassland at an elevation of approximately 9,500 feet (fig. 12). Although annual precipitation averages about 25 inches, the growing season is confined to about 90 days and soils are generally deep and fertile. Under such conditions seeding is usually successful, provided competition from native vegetation is substantially reduced or eliminated.

Two approaches to interseeding were followed: (1) broadcasting alsike clover seed on weedy grassland that had been sprayed with herbicide to reduce forb competition; and (2) broadcasting the seed over native plant cover with no attempt to reduce plant competition. Half

Figure 12.--Weedy grassland on Black Mesa Experimental Forest and Range in western Colorado. Alsike clover was interseeded here and on other comparable sites in the vicinity.

the plots were broadcast with pellets that contained inoculum and seed, and the other half with seed inoculated in the usual manner.

In 1964, pellets were broadcast at a rate of 2.96 pellets per square foot. Pellets contained an average of 13 seeds. Seed that had not been pelleted was broadcast at a rate of 55 seeds per square foot.

The number of clover plants present per 100 square feet soon after the plots were seeded in 1964 and at the end of the following summer was as follows:

	August 31, 1964	October 14, 1965
	(Number)	
Pelleted seed:		
Sprayed	6	32
Not sprayed	91	68
Nonpelleted seed:		
Sprayed	45	108
Not sprayed	294	56

Application of herbicide 2 days prior to seeding evidently was detrimental to seedling emergence. By 1965, however, the number of plants had increased on sprayed plots and decreased on plots not sprayed. In 1964, plants on pellet-seeded areas were much fewer than those on plots broadcast with nonpelleted seed. By 1965, the number of plants from pelleted seed slightly exceeded that from nonpelleted seed on sprayed plots but not on unsprayed plots. Most important is the fact that, in August 1964, 44 percent of the seedlings from the pellets had developed nodules. Spot checks in 1965 revealed that the nodules persisted at least 1 year.

The test was repeated in 1965, but only with unsprayed plots. Plots were seeded in June, and examined on October 14, 1965. Clover seedlings on pellet-seeded plots averaged 11 plants per 100 square feet, as compared with 116 on plots broadcast with regular seed. In both instances, seedlings were fewer than those from 1964 seedings.

Results from these trials, while not conclusive, indicate the possibility of interseeding with a legume. The alsike clover used in this trial, although persistent, did not make the growth desired. It appears that a more suitable species should be tried. Of importance is the fact that pellets did provide protection to the Rhizobium bacteria, and inoculated clover seedlings developed from them.

Results of Aerial Seedings

Three relatively large aerial seedings were made to determine the success of pellet seedings on sites where procedures and species for successful planting are known and seeding projects are common. Sites ranged from semidesert rangeland with 13 inches annual precipitation to high mountains where precipitation averages 30 inches. Location and characteristics of the three sites are summarized in table 7. Livestock were excluded from all areas during these studies.

Each test of pellet seeding was accompanied by a comparable test of the method usually used to seed such land. Seed from a common lot was used in each comparison. The influence of weather or other conditions on seeding success was determined by means of the comparison, because under arid conditions failures from range seeding are not uncommon. Results from these seedings are summarized in table 8.

Tres Piedras Trial

The site for this trial was representative of depleted sagebrush range in the upper Rio Grande Valley. Thousands of acres of similar rangeland have been successfully planted to crested wheatgrass in that region over the past 15 to 20 years. Check seedlings for comparison were made by the same people and by the same method commonly used in project plantings.

Immediately prior to seeding, all of the 300-acre tract, with the exception of eight 5-acre plots, was plowed with a brushland plow. The unplowed plots were used to determine success of pellet seeding on an unprepared seedbed. In October 1963, two-thirds the area was pellet seeded from a twin-engine Beechcraft flying at an altitude of 400 to 800 feet above the ground, and using a conventional seed spreader. Pellets containing crested wheatgrass seed were broadcast at the rate of 93 pellets per 100 square feet.

Check plots totaling 80 acres were planted to crested wheatgrass with a rangeland drill. Four of the unplowed 5-acre plots were also seeded in this manner. Seed was drilled at 4.9 pounds per acre, or about 20 seeds per square foot, a rate commonly used in such seedings.

In April 1964, counts were made on the pellet-seeded areas. The average number per 100 square feet on each seedbed was as follows:

	Plowed	Unplowed
Seedlings	0.6	0
Pellet remains (soil particles comprising one-third or more of original pellet)	17	28
Seeds buried under pellet remains	5	9
Exposed seed	19	34

Table 7.--Location and characteristics of sites aerially seeded

Project	Location	Size of area	Vegetation type and condition	Estimated average annual precipitation	Elevation
		Acres		Inches	Feet
Tres Piedras	Northern New Mexico	300	Big sagebrush, depleted	13	7,800
Chacon-Luna	Northern New Mexico	240	Spruce-fir, burned-over	30	11,000
Santa Rita Experimental Range	Southern Arizona	406	Desert grass-shrub, sprayed to kill mesquite	13	3,400

Table 8.--Results from pellet seeding by airplane compared with those from methods commonly used

Project location, vegetation type, and kind of seedbed	Species and date seeded	Area seeded		Method of seeding		Seeding rate		Plant development		
		Pellets	Check	Pellets	Check	Pellets	Check	Date counted	Seedings from-- Pellets	Check
		Acres				Number per 100 square feet	Pounds per acre		Number per 100 square feet	
Tres Piedras, northern New Mexico Big sagebrush Plowed	Crested wheatgrass, October 1963	180	80	Broadcast by plane	Drilled	93	4.9	4/28/64 8/12/64 10/20/64 8/25/65	0.6 2.5 12.2 13.5	50.0 29.0 91.6 87.3
Unplowed	Crested wheatgrass, October 1963	Four 5-acre plots	Four 5-acre plots	Broadcast by plane	Drilled	93	4.9	4/28/64 8/12/64 10/20/64 8/25/65	0 0 .5 .05	6 2 7.5 1.8
Chacon-Luna, northern New Mexico Spruce-fir Burned over	Timothy and orchardgrass, October 1963	2 areas totaling 120 acres	2 areas totaling 120 acres	Broadcast by plane	Broadcast by plane	90	5.5	8/10/64 8/25/65	9.0 10.5	90.0 81.5
Santa Rita Experimental Range, southern Arizona Desert grass-shrub Sprayed to control mesquite	Boer and Lehmann lovegrasses, July 1964	120	22	Broadcast by plane	Hand broadcast	188	1.66	8/ 5/64 8/21/64 9/21/64 11/ 8/64 2/ 4/65 6/18/65 3/14/66	13.0 3.4 .5 .3 6.0 1.3 .2	186.4 12.2 2.0 2.0 24.0 8.0 .8
	Boer and Lehmann lovegrasses, June 1965	244	Five 4-acre plots	Broadcast by plane	Hand broadcast	104	1.66	3/16/66	.5	.4

Pellets had produced less than one seedling per 100 square feet—a poor stand. In comparison, 50 seedlings per 100 square feet were present on plowed land that had been drilled—a fair stand. Six plants per 100 square feet were present on unplowed plots that had been drilled. Exposed seed from pellets, as well as pellet remains, were most abundant on the unplowed plots.

Numbers of crested wheatgrass plants per 100 square feet on pellet seeded and drilled areas in October 1964 and August 1965 are shown below:

	Plowed	Unplowed
Pellet-seeded area:		
October 1964	12.2	0.5
August 1965	13.5	.05
Drilled area:		
October 1964	91.6	7.5
August 1965	87.3	1.8

A crested wheatgrass seeding in the big sagebrush type in northern New Mexico usually is considered successful if one plant per square foot becomes established. In October 1964, 1 year after the seeding was completed, an average of one plant per 8 square feet was present on the area plowed and pellet seeded (fig. 13). At that time new plants were developing, as indicated by the fact that 44 percent of the plants present were seedlings not more than 2 inches tall. Deficient rainfall in 1964 apparently delayed seed germination. Similar delay was evident on drilled areas, as 38 percent of the plants there were not more than 2 inches tall.

By August 1965, the number of plants from pellet seeding on plowed land had increased to one plant per 7.3 square feet, as compared with one plant per 1.2 square feet from drilling. All plants were at least 5 inches tall and apparently well established (fig. 14).

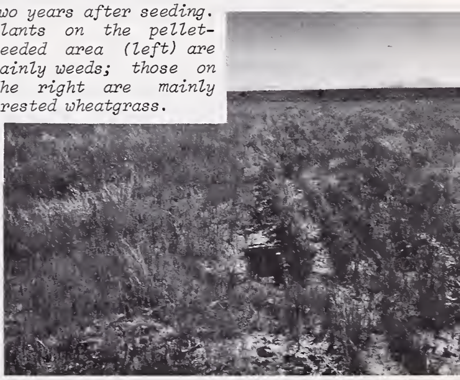
Where pellets had been broadcast over unplowed sagebrush land, the number of crested wheatgrass plants

Before plowing.

Figure 13.--Sagebrush range near Tres Piedras in northern New Mexico.

After plowing and seeding. The land on the left was pellet seeded; that on the right was seeded with a drill.

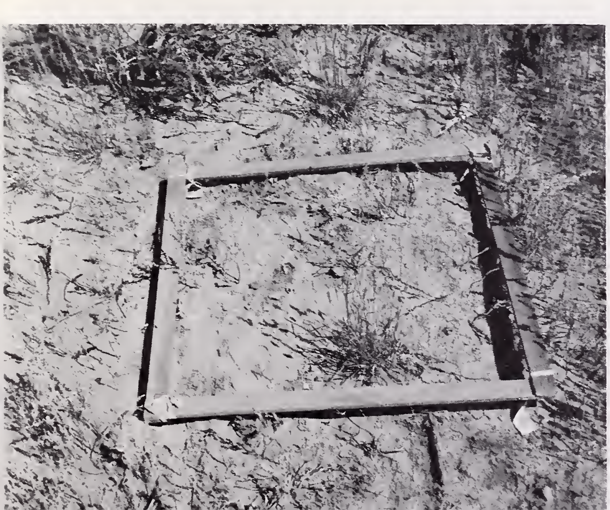
One year after seeding. Crested wheatgrass developed slowly. Most plants visible are native forbs.



Two years after seeding. Plants on the pellet-seeded area (left) are mainly weeds; those on the right are mainly crested wheatgrass.

Figure 14.--Comparative results of broadcasting pellets and drilling seed of crested wheatgrass on plowed sagebrush land.

Pellet seeded and drilled



Pellet seeded

Drilled

averaged one per 2,000 square feet in 1965. No seedlings were found on three of the four 5-acre plots seeded in this manner. Grass plants were only slightly more numerous on unplowed land that had been drilled. Three of those plots produced no seedlings; the fourth produced one seedling per 14 square feet. Past experience has shown that a satisfactory grass stand is seldom obtained on sagebrush-covered land unless the sagebrush is controlled by plowing, burning, or spraying with herbicide. Results of this test indicate that pellet seeding does not overcome the need for such control.

In summary, by the end of the second growing season one seedling was present for every seven pellets distributed on plowed seedbed. Since germination tests showed that 58 percent of the pellets would produce seedlings, it is estimated that one seedling was present for every four viable pellets distributed. On the whole, the number of plants was about one-sixth of that desired. The fact that the check area produced an adequate stand indicates that weather conditions were satisfactory for range seeding. Practically no crested wheatgrass plants became established on unplowed land, regardless of how it was seeded.

Chacon-Luna Trial

The Chacon-Luna area (fig. 15), located on the Carson National Forest near Taos, New Mexico, was selected as a site for testing pellet seeding because growing conditions there are generally favorable, grass is easily established in such areas, and it is representative of forest burns that are commonly revegetated by broadcasting grass seed into the ashes. Formerly timbered with Engelmann spruce and subalpine fir, the area lies at an elevation of 11,000 feet. Average annual precipitation is about 30 inches. A severe infestation of bark beetles necessitated logging trees of commercial value and cabling and burning the remaining trees to prevent spread of the infestation.

Seedings at Chacon-Luna were made on two sites totaling 240 acres, and located 1 mile apart. Half of each area was aerially seeded with pellets containing seed of timothy and orchardgrass. Height of flying varied from 100 to 400 feet, depending on the topography.

To provide a check, seed from the same lot used in manufacture of pellets was spread by airplane over the other half of each area. Seeding rate was 1.5 pounds of timothy and 4 pounds of orchardgrass per acre. Theoretically, those rates provided a total of about 100 seeds per square foot.

All areas were seeded during the week of October 21, 1963. Counts made the day after seeding was completed, revealed an average of 90 pellets per 100 square feet.

The following numbers of plants per 100 square feet were counted in August 1964 and August 1965:

	Timothy	Orchardgrass	Total
Pellets			
August 1964	4.5	4.5	9.0
August 1965	9.0	1.5	10.5
Seed only			
August 1964	20.0	70.0	90.0
August 1965	45.0	36.5	81.5

Pellet seeding produced about one-tenth of a stand, based on a standard that one established plant per square foot is needed to provide a satisfactory stand. One seedling developed for every nine pellets distributed, or for every seven viable pellets as determined in the laboratory. The fact that the stand produced by the usual method of seeding did approach the desired goal indicates that conditions were generally favorable for seeding.

Seedlings of both species were about 6 inches tall when counted in August 1964. One year later, plants were nearly 40 inches tall and apparently well established (fig. 16). Timothy plants became more abundant as orchardgrass plants decreased between the two dates of observation.

Santa Rita Trials

These seedlings were made on 406 acres of semidesert grass-shrub range on the Santa Rita Experimental Range, 35 miles south of Tucson, Arizona. The area was occupied by a dense stand of mesquite that had virtually

Figure 15.--One of the Chacon-Luna sites. Commercial timber had been logged, and the remaining trees cabled and burned prior to seeding to prevent spread of bark beetles. Pellets were broadcast over the distant part of the burn; regular seed of timothy and orchardgrass were broadcast over the area in the left foreground. Logging roads are clearly evident.

Figure 16.--

Sparse stand of orchardgrass and timothy on burned-over spruce site seeded with pellets. Most of the plants visible are native forbs and sedges. Photo was taken in August 1965 when plants were nearly 2 years old.

Good stand of orchardgrass and timothy obtained by broadcasting seed on the burn. Photo was taken in August 1965 when plants were nearly 2 years old.

Detail of area seeded with pellets. Plants of orchardgrass and timothy are widely scattered.

Detail of area seeded with regular seed. Orchardgrass and timothy plants form a relatively dense stand.

Figure 18.--Loading pellets into the aircraft used in the Santa Rita seeding. The disseminator (on belly of plane) was specifically designed to distribute pellets. The small propeller (arrow) ahead of the disseminator operates an auger that delivers pellets from the hopper to the disseminator.

eliminated the grass (fig. 17). Located in a 13-inch rainfall belt, it is typical of vast areas of arid rangeland in the southwest.

The usual practice in seeding such areas is to kill mesquite with 2,4,5-T, and broadcast seed of Lehmann or Boer lovegrass on an undisturbed seedbed. These seeds are exceptionally small, and no cultural treatment is needed to cover them. A high proportion of Lehmann lovegrass seed is hard or dormant. Seedlings emerge periodically whenever moisture is available but survival and growth require adequate moisture over several weeks. Nearby areas of the experimental range had been successfully seeded prior to these pellet seeding trials.

In this study, seedings were made both in 1964 and 1965 to increase the likelihood of success. The entire area was sprayed with 2,4,5-T in May 1964 and again in May 1965 to kill the mesquite. Most mesquite were killed. In early July 1964, at the close of the period usually characterized by drought, 120 acres were seeded with pellets of Lehmann and Boer lovegrasses at the rate of 188 pellets per 100 square feet. The pellets, 1/4 inch in diameter, were distributed from a Snow S2A aircraft (fig. 18) equipped with a disseminator especially designed by Lytle S. Adams of Tucson, Arizona. Flying altitude was approximately 100 feet.

As a check, regular seed of Boer and Lehmann lovegrasses were broadcast on 22 acres with a cyclone seeder at the rate of 1 pound and 2/3 pound per acre, respectively. Check seedings were made on strips 90 feet wide, through, but not superimposed upon, the pellet-seeded area.

In June 1965, 244 acres were seeded with 3/8-inch pellets of the same grasses and by the same general methods used in 1964. Some pellets were distributed in 1965 with a conventional spreader. Flying height was increased to 600 to 1,500 feet to gain more uniform distribution of pellets, and to assure that pellets reached terminal velocity before striking the ground. Rate of seeding, as determined from field count, averaged 104 pellets per 100 square feet. Depth of pellet penetration was measured on numerous lime-covered plots immediately after pellets were distributed.

Seed was broadcast on check plots by the same methods and at the same rates as in 1964, except that five 4-acre plots were used for comparative purposes. They were located immediately outside the pellet-seeded area.

On August 5, 1964, 1 month after the initial seedings were made, more seedlings were evident than at any other time.

On the areas seeded July 8, 1964, the number of seedlings per 100 square feet and the amount of rainfall received in 1964 between counting dates were as follows:

	Pellets (Number)	Seed only (Number)	Rainfall (Inches)
1964:			
August 5	13.0	186	3.69
August 21	3.4	12	1.06
September 21	.5	2	7.35
November 8	.3	2	1.55
1965:			
February 4	6.0	24	--
June 18	1.3	8	--
1966:			
March 14	.2	.8	--

Pellet seeding produced relatively few seedlings as compared with the number from regular seed. Rainfall of 3.69 inches between date of seeding (July 8) and when seedlings were first counted (August 5) caused many seeds to germinate. Subsequent rains during the summer ap-

Figure 17.--Dominant vegetation on the Santa Rita seeding site is mesquite, cholla, pricklypear cactus, and burroweed. Native perennial grasses are sparse. Note defoliation of mesquite from herbicide applied 2 months earlier. Photo was taken soon after the area was seeded in mid-July 1964.

parently were not conducive to seedling development. New seedlings that developed from fall and winter rains, counted February 4, 1965, also were short lived. Few plants were present 1 year after the first seeding was made.

On the areas seeded in 1965, few plants developed, either from pelleted or nonpelleted seed. On March 16, 1966, only 23 plants per acre were counted on the pellet-seeded area, and 168 per acre on those broadcast with nonpelleted seed.

Rainfall following the June seeding was much below average and poorly distributed. Two days after they were seeded pellets were partly melted by 0.35 inch of rain. An additional 0.85 inch, which fell intermittently prior to July 11, completely melted most pellets but failed to cause seed germination. Rainfall during the next several weeks was scant. No seedlings were found when the areas were inspected in November 1965, and few plants were evident 1 year later.

Experience has shown that, under semiarid conditions, Lehmann lovegrass in particular may spread readily from seed produced by a few plants. Also, seed may lay dormant until adequate moisture is available. Therefore, all stands could thicken in the future.

Numerous plots 2 feet square were coated with a thin layer of lime just before pellets were distributed in 1965 to study pellet penetration (fig. 19). Disposition of pellets that fell within those plots was determined, including the depth to which they penetrated. Hardness of the ground surface of each plot was estimated and classified. Surface soil was extremely dry at seeding time.

Based on all plots on which observations were made, 6 percent of the 3/8-inch pellets were more than half buried upon impact, 13 percent were partly but less than half buried, and 81 percent lay on the ground surface (table 9). Pellets penetrated loose, sandy soil more readily than other soils — 14 percent were more than half buried and 22 percent were partly but less than half buried. Of the pellets that fell on a hard soil surface, only 11 percent remained in pits made upon impact, and 2 percent were partly buried.

In supplemental tests in which pellets were impelled at or greater than terminal velocity into a moist, loamy soil, all pellets were at least partly imbedded in the soil but none was completely buried.

Results of these tests indicate that few pellets are likely to be buried completely when distributed from an airplane, except, perhaps, in loose, powdery, dry soil.

Comparative Costs of Seeding

Cost of pellet seeding ranged from $7.81 to $14.76 per acre, as compared with $3.71 to $7.56 per acre for other methods (table 10). Although these costs are substantially higher than they would be for larger seedings, the costs for pellet seeding probably will remain higher than for other methods until the costs of manufacturing and distributing pellets are substantially reduced.

Cost of pellet manufacture, computed by the manufacturer to be $0.0845 per pound, accounted for 66 to 74 percent of the total cost of pellet seeding. That cost

Figure 19.--Sample plots used in measuring pellet penetration on the Santa Rita Experimental Range.

Pellets formed pits and commonly became partly imbedded in loose, sandy soil.

Penetration of pellets into a moderately hard soil surface was negligible.

Table 9.--Disposition of pellets aerially distributed on semidesert, grass-shrub range in June 1965, including their resting place, depth of penetration, and initial burial under different ground surface conditions, Santa Rita Experimental Range

Disposition of pellets	Nature of soil surface and number of pellets observed			
	Loose (83)	Firm (257)	Hard (96)	All plots (436)
	Percent			
Resting place:				
On surface	36	55	89	59
In pits	64	45	11	41
Depth of pits containing pellets:				
0.1 inch	2	2	9	2
.2 inch	4	8	64	10
.3 inch	8	40	18	30
.4 inch	49	39	9	40
.5 inch	26	11	0	15
.6 inch	11	0	0	3
Portion of pellets initially buried:				
In pits--				
None	43	57	82	54
Less than half	34	30	18	31
More than half	23	13	0	15
All pellets--				
None	64	80	98	81
Less than half	22	14	2	13
More than half	14	6	0	6

Table 10.--Comparative per-acre costs of seeding with pellets and by other methods at three field locations[1]

Cost items	Tres Piedras		Chacon-Luna		Santa Rita			
	Pellets	Regular method	Pellets	Regular method	Pellets		Regular method	
					1964	1965	1964	1965
Seed	$0.61	$1.45	$0.41	$2.94	$0.96	$0.55	$5.25	$3.25
Pellet manufacture	9.30	--	6.00	--	5.35	10.90	--	--
Pellet or seed distribution by airplane	2.43	--	2.33	.63	1.25	2.28	--	--
Miscellaneous (loading ground control, etc.)	.99	--	.32	.14	.25	1.03	--	--
Drilling or broadcasting seed	--	6.11	--	--	--	--	1.48	1.05
Total cost	$13.33	7.56	9.06	3.71	7.81	14.76	6.73	4.30

[1]Exclusive of ground preparation.

was based on production of 80 lots of pellets totaling nearly 75,000 pounds. Individual lots ranged from 5 pounds to 19,200 pounds. In most instances two or more lots were produced at a particular time, the only difference being in the kind of seed or additive used.

Aerial distribution of pellets also was relatively expensive—$1.25 to $2.43 per acre. Distribution accounted for 15 to 26 percent of the total cost of pellet seeding. Weight of the earthen pellets is responsible for much of that cost. Use of a lighter pellet matrix could reduce that cost considerably.

Also important is the fact that cost of distributing 1/4-inch pellets was about $1 per acre less than that for 3/8-inch pellets. This difference points up the cost advantage of seeding small pellets wherever they are suitable.

Costs listed by Hull (1959) for pellet seeding ranged from $2 to $11.40 per acre. The latter included cost of ground preparation, and all costs were based on the application of one pellet per square foot.

If the differences in success between the methods are ignored, allowable cost of pellets to meet the cost of seeding by the regular methods would be as follows:

	Allowable cost per pound	Size of pellet
Tres Piedras	$0.0321	5/16 inch
Chacon-Luna	.0092	5/16 inch
Santa Rita (1964)	.0674	1/4 inch
Santa Rita (1965)	.0034	3/8 inch

These would compare with the cost of $0.0845 per pound of pellets used in these tests. Only for the 1964 seeding on the Santa Rita Experimental Range were actual and allowable costs of pellet manufacture reasonably similar. In that test 1/4-inch pellets were applied at a rate of 63-1/3 pounds per acre, and the landing strip was only 4 miles from the seeded area. In 1965 pellets 3/8 inch in diameter were applied at a rate of 129 pounds per acre on land adjacent to the 1964 seeding. The increased weight of pellets practically doubled the cost of distribution, as well as the cost of manufacture. Consequently, total cost of the 1965 seeding was much higher than that of 1964, even though fewer pellets per acre were applied.

Findings from these and other tests indicate that, to produce grass stands comparable to those from seeding methods ordinarily used, several viable pellets per square foot must be applied. Cost of applying earthen pellets at that rate under most circumstances would be prohibitive.

Discussion

Theoretically, a pellet could provide the essentials for successful seed germination and seedling establishment. The principal weaknesses of the method brought out in this investigation were (1) the rapid melting of pellets and resulting lack of seed coverage, and (2) the cost.

Except for a few grasses and legumes, viability of most pellets when manufactured was relatively high—higher than that reported by other investigators (Hull et al. 1963). Large-seeded grasses were the most troublesome. Two factors were involved: first, the large seeds were more difficult to mix uniformly with clay; second, they were more susceptible to damage from breakage or compression during the pelleting process. Similar seed damage to large-seeded species was reported by Bleak and Phillips (1950) and Stevenson (1949). Damage to seed presumably results from the secondary effects of pressure or a curtailed oxygen supply according to Hull and others (1963).

Pellets of small-seeded species exhibited high viability, probably because the greater number of small seeds are readily and uniformly mixed with pelleting clay, thus increasing the probability that each pellet will contain undamaged seed.

Most pellets remained viable for several months, particularly if dried soon after manufacture. Evidence indicates tha pellet moisture content should be reduced to 5 or 6 percent soon after manufacture and maintained at that level during storage. Seed of certain species, such as smooth brome and Turkestan bluestem, apparently are more susceptible than others to damage from excess moisture and, possibly, from excess heat.

Number of pellets per pound varied with size of pellet, kind of seed, and amount of pellet breakage. In general, the number of pellets per pound was comparable to numbers reported by other investigators (Wagner 1949, Bleak and Phillips 1950, Tisdale and Platt 1951).

Pelleting facilitated uniform distribution of very small seeds, such as those of lovegrasses that usually are seeded at the rate of 1 pound or less per acre.

Pelleting effectively deterred consumption of seed by deer mice in the laboratory. This finding suggests that pelleting may provide a practical means for reducing loss of seed to rodents. Further investigation appears warranted, not only with grass seed, but with tree and shrub seeds which commonly are destroyed or consumed by rodents.

Though alternate freezing and thawing had little effect on clay pellets, artificial rainfall or relatively high intensity melted them quickly. Rapid melting is regarded as a weakness because it exposes the pelleted seed or roots of young seedlings. Pellets melted more slowly

under small amounts of rain applied frequently. In one test, only 12 percent of the pellets were completely melted after 21 applications of artificial rain in amounts of 1/4 inch.

Of the various modifications to reduce melting rate or to improve moisture-absorbing characteristics of pellets, none proved entirely satisfactory. Results were encouraging, however, and pointed to the need for further investigation along similar lines.

Incorporation of certain lightweight materials effectively reduced pellet weight. It is conceivable that further research could provide a pellet only a third or fourth as heavy as the regular clay pellet.

That compressed earthen pellets can serve effectively as carrriers of legume inoculant is considered significant. Legume-inoculating bacteria remained alive and functioned well for at least 8 months when in contact with pelleted seed. Results of field tests aimed at establishing clover in a legume-poor mountain grassland through use of inoculated pellets were promising. Further research in this field appears justified.

Aerial seedings of pellets produced thinner stands of grass than did conventional methods. Nevertheless, on one study area one seedling became established for every four viable pellets distributed. On another, one seedling was established for every seven pellets distributed. Where pellet seeding failed completely, stands obtained by conventional methods likewise were generally unsatisfactory. Results from pellet seeding probably would have been more comparable to those from other methods if a larger number of pellets per acre had been applied.

Pellets made small pits, and many were partly buried upon impact in loose, sandy soil in tests made in conjunction with aerial seedings on desert grass-shrub range. Further observation revealed that rainfall increased burial of pellets that stayed in pits. In most instances, however, pellets lay unburied on the soil surface. These findings, though in agreement with those of Wagner (1949), are at variance with those of Tisdale and Platt (1951).

In the field as well as in the laboratory, rapid melting of pellets and lack of seed coverage were believed to be partly responsible for fewer seedlings from pellets. These findings are in accord with those of Hull and others (1963) who observed that, as pellets were moistened by rain, the soil covering softened and spread out into a rounded mound, the seeds usually were left with little or no covering, and the disintegrated pellet mound was more susceptible to rapid drying than the surrounding soil surface.

Fabrication of a lightweight but durable pellet that would provide a suitable micro-environment for seed germination and early seedling development seems possible. It would, however, require further research.

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Chadwick, Howard W., Turner, George T.,
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Earthen pellets containing seeds were tested for seeding rangelands in Arizona, New Mexico, and Colorado, 1963-65. Laboratory and greenhouse tests showed that pellets containing small seeds retained viability when properly handled; large seeds usually were damaged by pelleting process. Field-plot trials and aerial seedings showed that some seedlings developed from seedings made with pellets but seedling stands were more sparse than from methods usually used.

Key words: Rangeland, pellet seeding, Southwest.

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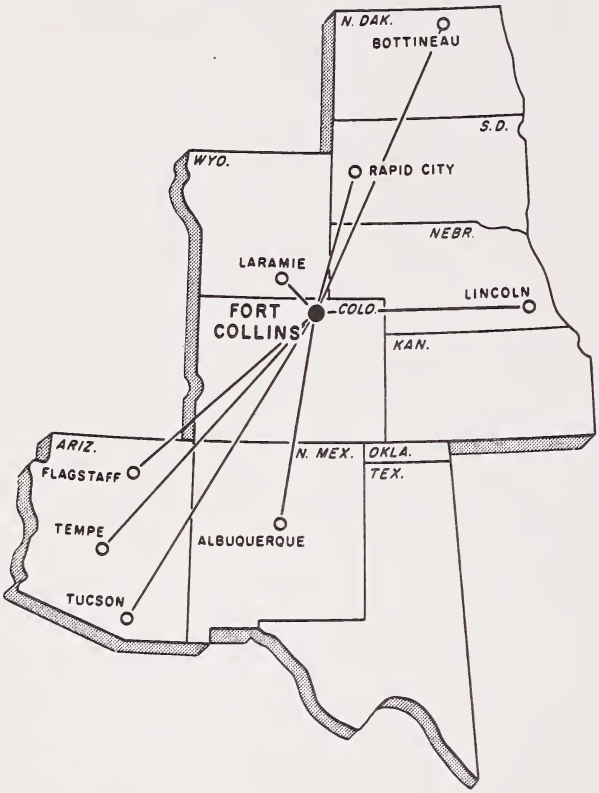
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